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Battery Charging Using Doubly Fed Induction Generator Connected to Variable Speed Wind Turbine

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Abstract

Wind energy, one of the renewable energy sources can be used as an alternate fuel. The main objective of this paper is to make the system with a variable speed wind turbine using DFIG to supply the local loads. The proposed system using DFIG is modelled and simulated in MATLAB. The slip power from the DFIG in its super synchronous mode of operation can be used for battery charging through back to back connected converters. Here machine side converter acts as the rectifier and the battery side converter as inverter. The simulations analysis for battery charging is done here using MATLAB Simulink model.

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Keywords: battery charging; DFIG; variable speed wind turbine

1. Introduction

Wind power is the conversion of wind energy into a useful forms of energy such as wind pumps,wind mills, wind turbines etc. The DFIG which is used for variable wind speed operations can be used for battery charging. The variable speed DFIG has several advantages instead of fixed speed machine like: reduce mechanical stress, dynamically compensate torque, reduce converter rating and reduce cost and losses in result of that an improved efficiency [4].

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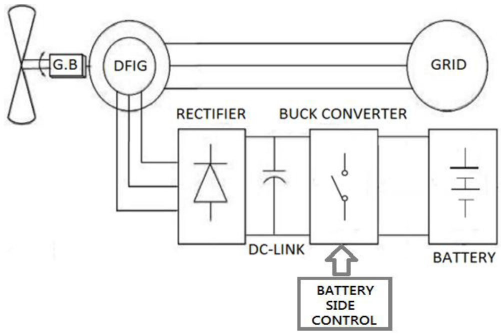

Fig. 1 Battery Charging Circuit for Wind Turbine DFIG

The stator terminals of DFIG are connected directly to the grid whereas the rotor terminals are connected to the battery through a diode rectifier and a buck converter as shown in Fig. 1. The battery used is Nickel Metal Hydride whose discharge profile curve is shown in Fig. 2.

2. Wind Turbine Model

Based on a first principle using conservation of mass and conservation of energy in a wind stream, the maximum extractable power from wind is defined as Eqn (1). The theoretical maximum power extractable from wind is 0.59 times the power contained in wind. The power contained in a wind is given by the kinetic energy of the flowing air mass per unit time.

$$\boldsymbol{P_{max}} = \frac{8}{27}\boldsymbol{\rho A V_{\infty}^{3}} = \frac{16}{27}\boldsymbol{P_{m}} \quad (1)$$

$$\boldsymbol{P_{m}} = \frac{1}{2}\boldsymbol{\rho A V_{\infty}^{3} C_{p}} \quad (2)$$

Where, $\boldsymbol{P_m}$ is the mechanical power contained in wind (Watts), $\boldsymbol{\rho}$ is the air density, $\boldsymbol{A}$ is the rotor area, $\boldsymbol{V_\infty}$ is the wind velocity, $\boldsymbol{C_p}$is the power coefficient of the wind turbine.

3. Battery Characteristics

Nickel–Metal Hydride battery (NiMH) is used in simulation. It is a rechargeable battery. The typical specific energy for small NiMH cells is about 100 Wh/kg. Charging voltage of NiMH is in the range of 1.4–1.6 V/cell. NiMH batteries have a relatively low internal resistance (IR). This allows NiMH batteries to have excellent high rate performance. The IR of fresh, fully charged NiMH batteries is typically less than 50 milliohms. During discharge, the battery IR will stay relatively constant until near end of life where it will rise sharply. The discharge profile for a battery discharged at the 5-hour rate is shown in the Fig. 2. The initial drop from an open-circuit voltage of approximately 1.4 volts to the 1.2 volts occurs [2].

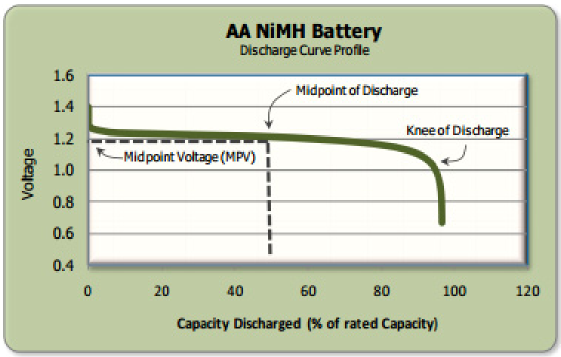

Fig. 2 Battery Discharge profile

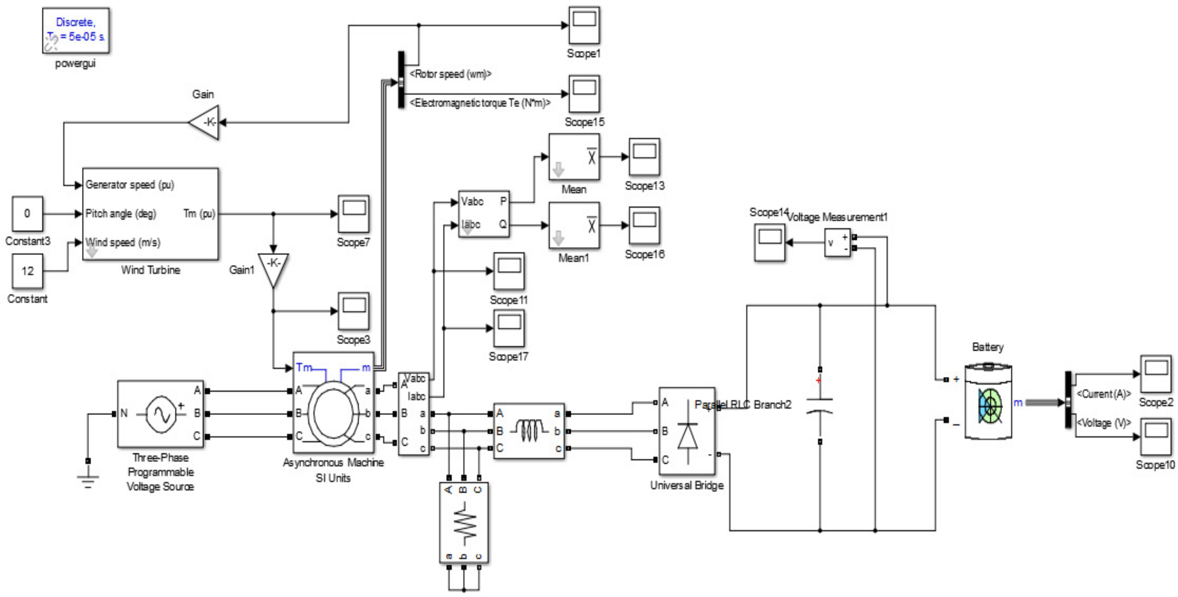

Fig.3 Simulink model for battery charging in open loop circuit

4. Simulation Model

A MATLAB/Simulink simulation analysis for battery charging is presented here to demonstrate the system performance in different operating conditions. The operating conditions are based on the change in wind velocity, wind velocity of 25m/s is taken here for analysis. A 5HP slip ring induction machine is taken as DFIG, connected to variable speed wind turbine. The rated capacity of the battery is taken as 10Ah. The initial battery voltage is taken as 45.8V.

In open loop model shown in Fig. 3 the output of DFIG is connected to a diode bridge rectifier through RL filter. The output of diode rectifier is connected to the input terminal of the battery through DC link. In open loop model there is no control algorithm applied to control the DC link voltage. In this case battery may over charge, depending on the wind speed. In closed loop model, a control algorithm using PI controllers is used to maintain the DC link voltage constant. A buck converter is used in order to control the DC link voltage. The voltage available for charging at the input terminal of the battery is taken as feedback. If it exceeds from a predefined value (in this model 53V) the PI controller generates switching pulses for the buck converter to step down the voltage, which prevents the overcharging of the battery.

5. Simulation Results

Both open loop and closed loop MATLAB simulation results are shown in this section. Fig. 4, Fig. 5, Fig. 6, Fig. 7 and Fig. 8 show the open loop results and Fig. 9, Fig. 10 and Fig. 11 show the closed loop results. The rotor speed in super synchronous mode of operation is shown in Fig. 4. Fig. 5 and Fig.6 show the waveforms of rotor voltage and rotor current.

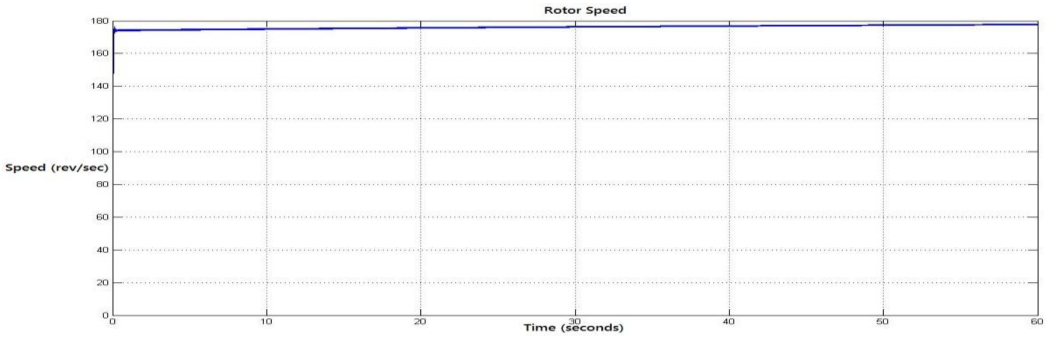

Fig. 4 Rotor Speed

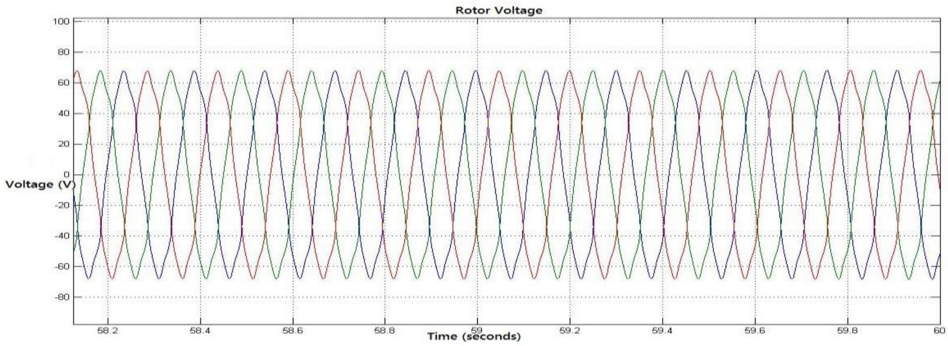

Fig. 5 Rotor Voltage

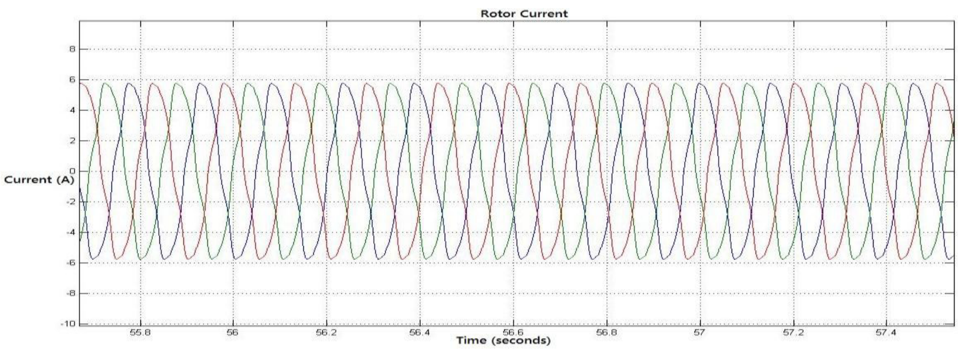

Fig. 6 Rotor Current

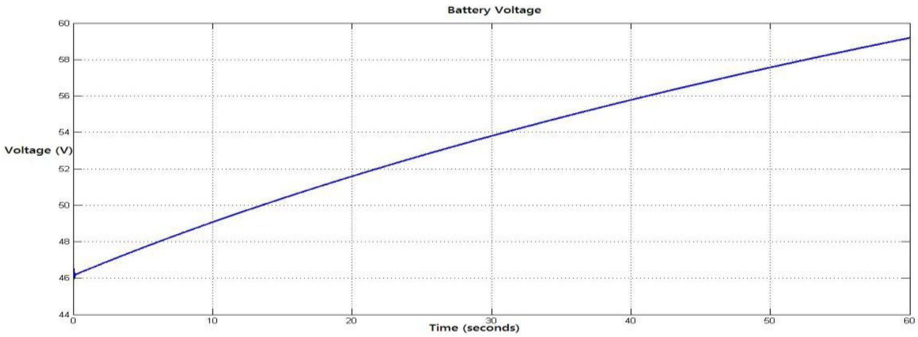

Fig. 7 Battery Voltage during Charging

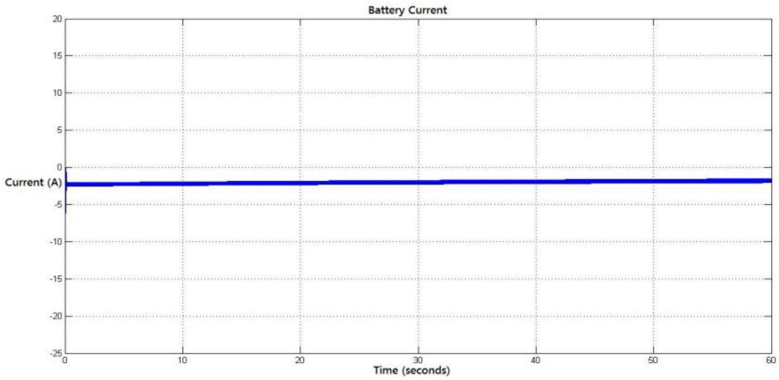

Fig. 8 Battery Current

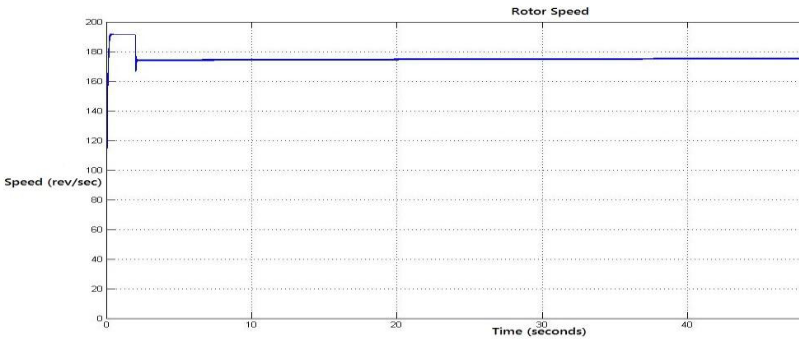

Fig. 9 Rotor Speed

Fig. 7 and Fig. 8 show the battery charging voltage and current respectively. It shows the overcharging of the battery in open loop model which is being corrected by using PI controller in closed loop model, which is shown in Fig. 10 and Fig. 11. It can be observed in closed loop that battery charging voltage is not exceeding a certain limit and trying being constant after 53V in closed loop simulation analysis.

6. Conclusion

Simulation analysis for 5HP slip ring induction motor is done using Matlab/Simulink and models for battery charging for both open loop and closed loop analysis. Power is extracted from DFIG in the super synchronous mode of operation. In open loop simulation analysis, rotor speed is increasing continuously with increase in the wind velocity. The battery charging voltage is also increasing beyond its defined rating, if rotor voltage of DFIG is more due to high wind velocity. In closed loop simulation analysis rotor speed is maintained constant and the battery charging voltage is being regulated using PI controller. 53V is considered as the reference value and compared with the output voltage across the buck converter. PI controller is generating the error signal, and the switching pulses are generated using PWM technique.

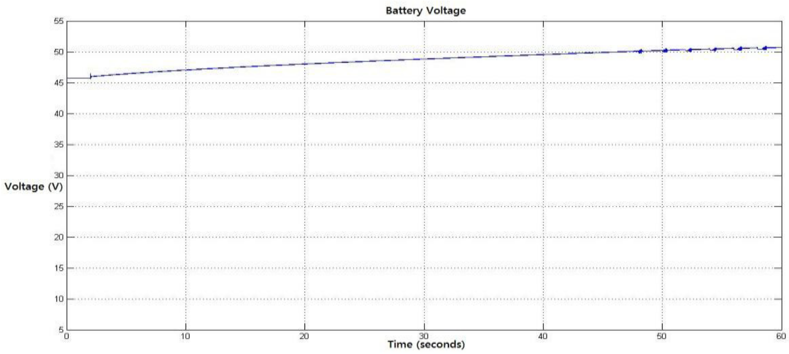

Fig. 10 Battery Voltage during Charging

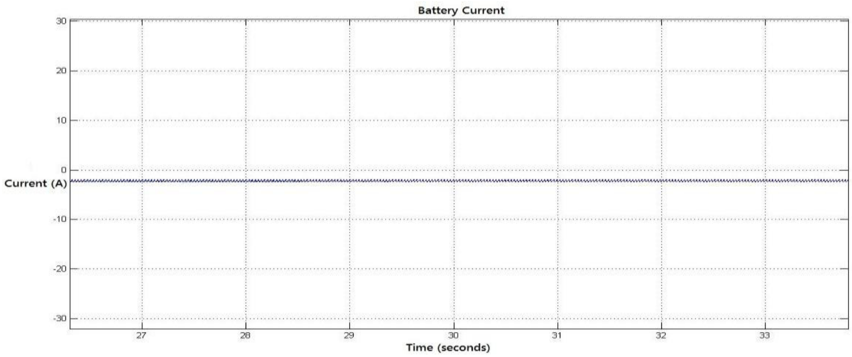

Fig. 11 Battery Current

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